RB13

ADVANCES IN ARCTIC ICEBREAKER DESIGN

BY JOHN T. STUBBS
KIN K. TUE-FEE
ARNO J. KEINONEN

DOME PETROLEUM LIMITED

PAPER PRESENTED TO THE SYMPOSIUM ON
SCIENCE AND ARCTIC HYDROCARBON
EXPLORATION: THE BEAUFORT EXPERIENCE

WHITEHORSE, YUKON, CANADA

SEPTEMBER 29-30, 1983

POLAR
PAM
4707

POLARPAM

Pam:629.124.791.2 STU

Rec'd: 4 April 1984
Order No.:
Price: WF
Acc. No.: F.E.A.R.O.

1. SUMMARY

The economics of resource exploration and production in the Arctic regions dictate the need for cost effective icebreaker vessel support. Recent developments and extensive full scale performance evaluations show convincingly that the introduction of innovative design features are effective in meeting this need. As a result, the power requirements for an icebreaker with year-round Arctic operational capabilities are being reduced considerably by actual demonstrations of icebreaking performance of the following two ships, the Canmar Kigoriak and the Robert LeMeur.

In this paper, the authors discuss the novel design features of the Canmar Kigoriak, industry's first purpose-built Arctic icebreaker, specifically; hull form, ice management systems, manoeuvreability, propulsion requirements and resultant performance.

On the basis of the very successful full scale performance results of the Canmar Kigoriak, a second generation Arctic icebreaker, the Robert LeMeur, has been designed, built and evaluated. The systematic variations from the Kigoriak proven design features incorporated within the Robert LeMeur are outlined.

The Kigoriak and Robert LeMeur Research Programs were specifically aimed at evaluating and assessing features of these two ships in actual Arctic conditions and provide unique full scale knowledge for the development of future operations of polar class vessels.

Future developments based upon research results are presented in concept form for a polar icebreaker and icebreaker/oil tanker.

2. INTRODUCTION

Icebreaker development over the past 100 years has focused upon providing support to commercial ice transiting shipping activities. The required icebreaker performance specifications have therefore evolved from experience gained in performing such duties.

The use of icebreakers supporting frontier resource exploration activities in the Arctic has identified the need for ships which are far more ice-capable and cost effective. To date, the Canmar Kigoriak and the Robert LeMeur are the largest proven purpose built icebreakers in operation to support offshore resource exploration in the Arctic. A new design philosophy has been pursued to meet the mission profile requirements which incorporates features which differ radically from past icebreaker design practice. These features are outlined in the following sections and an assessment of their effectiveness is given based upon testing and evaluation under actual full scale Arctic conditions.

BOREAL INSTITUTE
LIBRARY

56173

PRINCIPAL PARTICULARS

FEATURE	MEASUREMENT
LENGTH (OVERALL)	90.0 m
LENGTH (AT WATERLINE)	84.2 m
BREADTH (MOULDED)	17.25 m
BREADTH (OVER REAMERS)	19.25 m
DEPTH	10.0 m
DRAFT (MAXIMUM)	8.5 m
SHAFT POWER (HULL LUBE OFF)	12.2 MW
SHAFT POWER (HULL LUBE ON)	11.8 MW

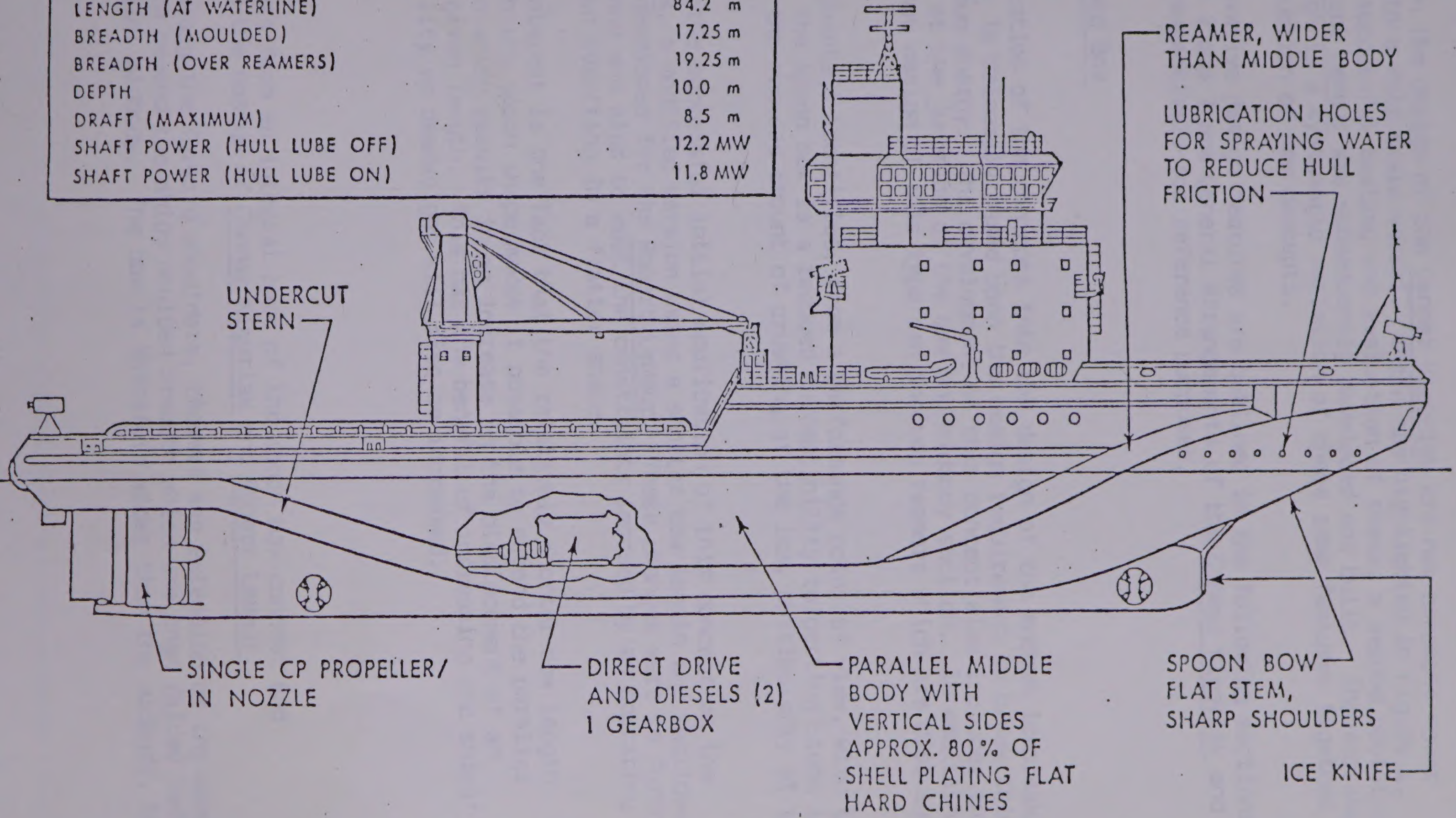

UNDERCUT STERN
REAMER, WIDER THAN MIDDLE BODY
LUBRICATION HOLES FOR SPRAYING WATER TO REDUCE HULL FRICTION
SINGLE CP PROPELLER/ IN NOZZLE
DIRECT DRIVE AND DIESELS (2) 1 GEARBOX
PARALLEL MIDDLE BODY WITH VERTICAL SIDES APPROX. 80 % OF SHELL PLATING FLAT HARD CHINES
SPOON BOW FLAT STEM, SHARP SHOULDERS
ICE KNIFE

FIG. 1: KIGORIAK GENERAL ARRANGEMENT

3. INNOVATIVE DESIGN FEATURES

Embodied in the design of the Canmar Kigoriak are new concepts never before built into a full scale vessel. These are highlighted in Figure 1. Based upon the successful testing and evaluation of these, a second prototype vessel, the Robert LeMeur was subsequently developed and built. Incorporated within her design is a systematic variation of these same features together with the introduction of new concepts.

These innovative design features are outlined in the following sections. Shown in Figure 2 and 3 are General Arrangements of the Canmar Kigoriak and Robert LeMeur respectively for reference purposes.

3.1 Spoon-Shaped Bow

The application of the concepts into the design of the modern icebreaker Canmar Kigoriak is primarily based upon the design requirement to break thick ice using minimum energy. The development of this concept also includes the sharp shoulder at the junction of the bow and midbody section. In addition, an icebreaker bow design of this type can include reamers which are discussed separately.

Another advantage identified, from a performance point of view, with the development of the spoon bow is a reduced susceptibility to getting stuck in the ice due to the reduced amount of crushing of the ice, particularly at the shoulders.

Following the successful initial application of this concept on the Canmar Kigoriak, a modified version using a shorter bow length and shallower bow angle was developed for the Robert LeMeur. These changes were to further reduce resistance and also to meet the constraints imposed by an operating draft limitation resulting in a flatter shape.

Also of interest is the fact that the relatively shorter bow length associated with the spoon shape makes it possible to extend the parallel midbody forward which results in an increase in the displacement of an icebreaker of given length. This has the benefit of increasing the ships' earning capability as deadweight will also be increased.

3.2 Reamers

The reamers form an integral part of the spoon bow concept and application in the design of Canmar Kigoriak and Robert LeMeur.

Located along the forward shoulders, reamers are extension of the spoon shaped bow form beyond the ships moulded breadth which are then faired back into the parallel midbody. The bow is therefore wider than the midbody, but only locally.

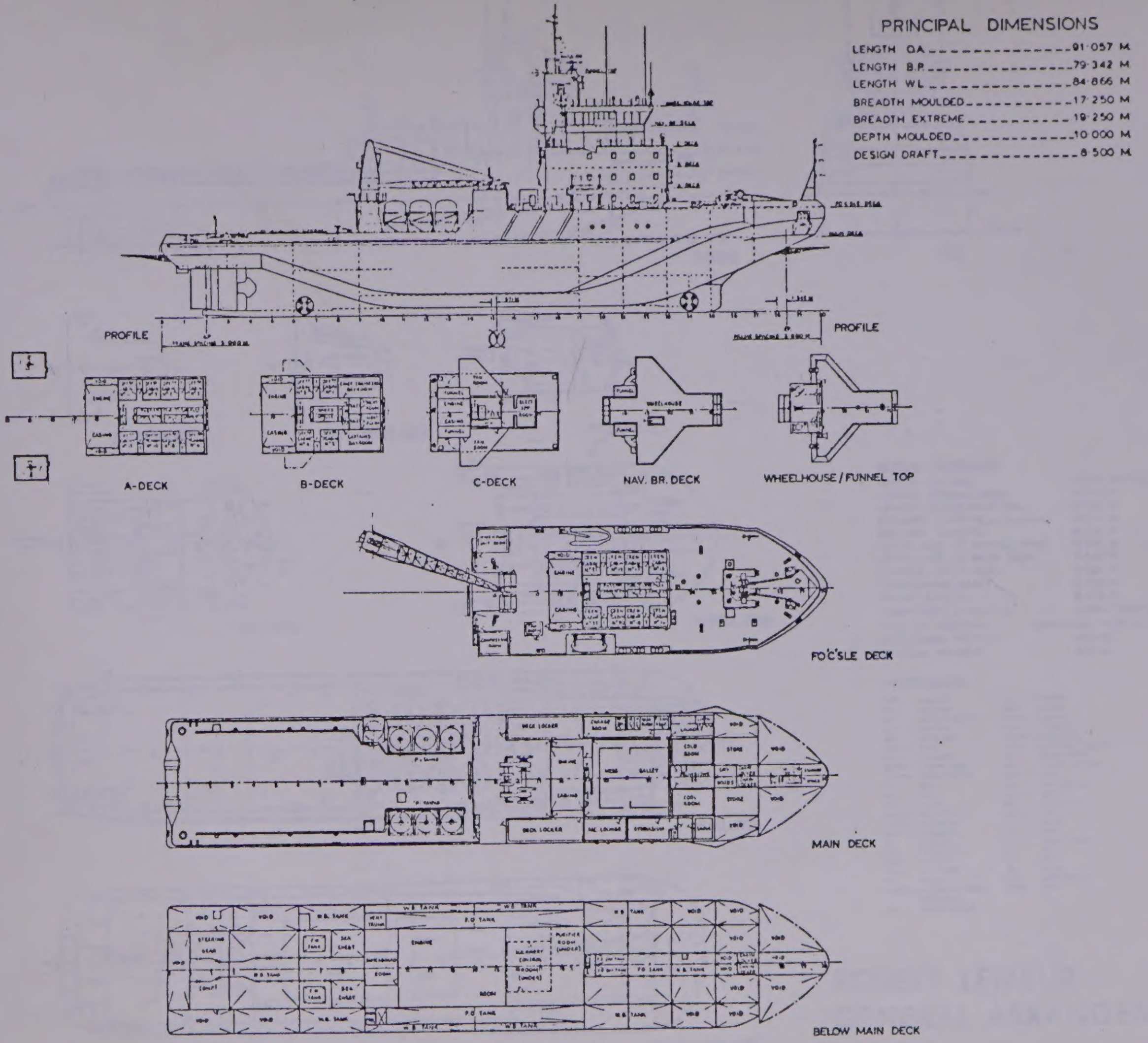
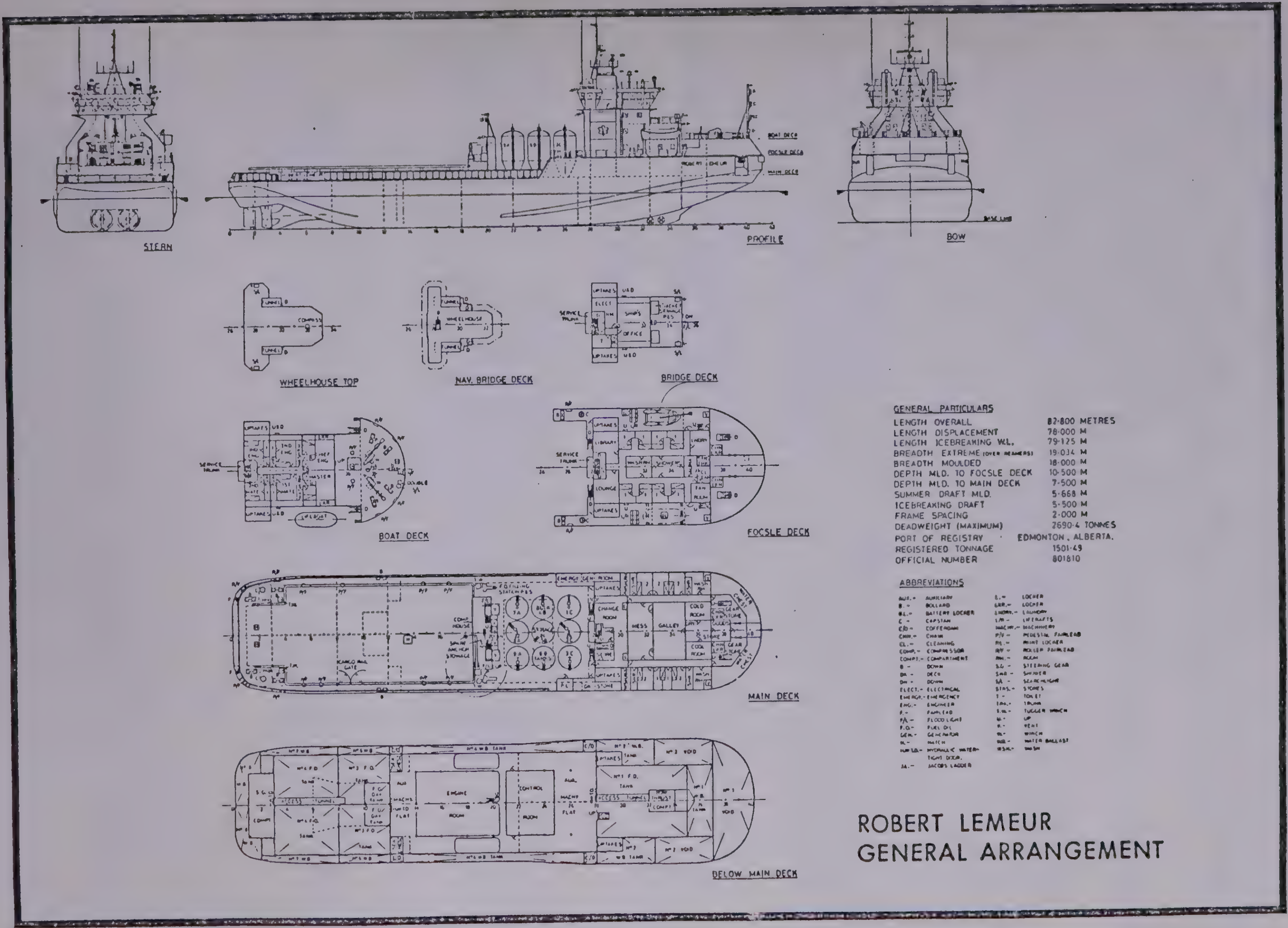

PRINCIPAL DIMENSIONS
LENGTH O.A. ---------- 91·057 M.
LENGTH B.P. ---------- 79·342 M.
LENGTH W.L. ---------- 84·866 M.
BREADTH MOULDED ---------- 17·250 M.
BREADTH EXTREME ---------- 19·250 M.
DEPTH MOULDED ---------- 10·000 M.
DESIGN DRAFT ---------- 8·500 M.
PROFILE
PROFILE
A-DECK
B-DECK
C-DECK
NAV. BR. DECK
WHEELHOUSE / FUNNEL TOP
FO'C'SLE DECK
MAIN DECK
BELOW MAIN DECK

FIGURE 2 CANMAR KIGORIAK GENERAL ARRANGEMENT



GENERAL PARTICULARS

LENGTH OVERALL	82·800 METRES
LENGTH DISPLACEMENT	78·000 M
LENGTH ICEBREAKING W.L.	79·125 M
BREADTH EXTREME (OVER REAMERS)	19·034 M
BREADTH MOULDED	18·000 M
DEPTH MLD. TO FOCSLE DECK	10·500 M
DEPTH MLD. TO MAIN DECK	7·500 M
SUMMER DRAFT MLD.	5·668 M
ICEBREAKING DRAFT	5·500 M
FRAME SPACING	2·000 M
DEADWEIGHT (MAXIMUM)	2690·4 TONNES
PORT OF REGISTRY	EDMONTON, ALBERTA.
REGISTERED TONNAGE	1501·49
OFFICIAL NUMBER	801810

ABBREVIATIONS

AUX. –	AUXILIARY	L. –	LOCKER
B. –	BOLLARD	LKR. –	LOCKER
B.L. –	BATTERY LOCKER	LNDRY. –	LAUNDRY
C –	CAPSTAN	L/R –	LIFERAFTS
C/D –	COFFERDAM	MACHY. –	MACHINERY
CHN. –	CHAIN	P/F –	PEDESTAL FAIRLEAD
CL. –	CLEANING	P.L. –	PAINT LOCKER
COMP. –	COMPRESSOR	R/F –	ROLLER FAIRLEAD
COMPT. –	COMPARTMENT	RM. –	ROOM
D –	DOWN	S.G. –	STEERING GEAR
DK. –	DECK	SHR. –	SHOWER
DN –	DOWN	S/L –	SEARCHLIGHT
ELECT. –	ELECTRICAL	STRS. –	STORES
EMERGY. –	EMERGENCY	T –	TOILET
ENG. –	ENGINEER	TRK. –	TRUNK
F. –	FAIRLEAD	T.W. –	TUGGER WINCH
F/L –	FLOODLIGHT	U. –	UP
F.O. –	FUEL OIL	V. –	VENT
GEN. –	GENERATOR	W. –	WINCH
H. –	HATCH	W.B. –	WATER BALLAST
H.W.T.D. –	HYDRAULIC WATER-TIGHT DOOR.	WSH. –	WASH
J.L. –	JACOBS LADDER		

ROBERT LEMEUR
GENERAL ARRANGEMENT

FIGURE 3

The widely recognized capability of breaking a track wider than the ships' beam is therefore introduced without the drawback of wedging the ship during astern operations.

Benefits associated with the use of reamers include increased lubrication and therefore reduced resistance along the ships' side and significant improvements in ship manoeuvreability in ice.

The advantages obtained from the use of reamers far outweigh the slightly greater breadth of track that must be broken.

For the purpose of studying the reamer, widths of 1.0 metre and 0.5 metre have been incorporated in the design of Canmar Kigoriak and Robert LeMeur respectively.

3.3 Ice Knife

Design considerations of the forefoot stopper at the base of the bow include the need to impact a splitting force into the consolidated section of a ridge or multi-year ice which has not failed in bending during bow ride-up. The ice knife must also be configured to prevent excessive ride-up/penetration of the ship resulting in getting stuck and/or beaching of the vessel.

In this context, different configurations have been built-in to the Canmar Kigoriak and Robert LeMeur for the purpose of obtaining a better understanding of the design requirements relating to the forefoot.

3.4 Parallel-Sided Midbody

The conventional icebreaker usually has a flared midbody to overcome the high resistance associated with ice crushing in the vicinity of the forward shoulders as well as for manoeuvreability considerations. Other disadvantages include an expensive, rather complex construction at the junction of bow and midbody. Since this design requirement is overcome by the spoon-bow with or without reamers, it is now possible to build icebreakers with parallel vertical sides.

This feature has therefore been adapted in both Canmar Kigoriak and Robert LeMeur for the purpose of testing and assessing this type of feature which will be prevalent in large transportation system vessels. It is also of benefit in that it facilitates the construction of these vessels with consequent reductions in capital cost and delivery time.

3.5 Stern Configuration

First introduced in the Canmar Kigoriak is the undercut stern which is designed to reduce the suction of ice into the ducted propellers as well as permit backing of the ship into heavy ice.

Performance results were mixed which resulted in the introduction of the propulsion island on the Robert LeMeur design. This feature is intended to reduce the amount of ice-propeller interactions in thick level ice ahead and whilst backing.

3.6 Ice Management Systems

These systems, varying widely in complexity and cost, are all primarily intended to reduce friction in one form or another.

Only a water lubrication system was incorporated in the Kigoriak design. This system, developed and applied for the first time by Dome/Canmar on a ship, has been extremely successful at reducing resistance and contributes in part to the fact that the ship's performance has exceeded even the most optimistic performance expectations.

The water lubrication system discharges a screen of water from strategically placed holes at the bow onto the snow/ice surface. Friction is therefore reduced with the added benefit that the greatest reductions in friction and therefore resistance occur with colder temperatures and/or thicker snow cover. The same system has been fitted on the Robert LeMeur with similar success.

Further enhancements in ice management systems incorporated into the Robert LeMeur have been previously discussed, by Churcher et al (1983).

These include hull lubrication below the waterline and a low friction hull coating to reduce resistance, the use of air bubbler systems to reduce ice-propeller interactions and a heeling system to improve manoeuvreability.

3.7 Propulsion System

The novel aspect of both the Canmar Kigoriak and Robert LeMeur has been the introduction of mechanical systems of standard design.

The Canmar Kigoriak is propelled by two diesel engines driving a single ducted controllable pitch propeller through a twin-input single output gearbox.

A single screw configuration was selected to overcome the problems of constantly milling ice experienced on the outboard screws of twin screw and triple screw icebreakers. The single screw is surrounded by a duct to give greater thrust at low speed and to provide protection to the propeller by limiting the size of ice blocks capable of interacting with it.

Following the very successful use of this system, a similar concept was adopted for the Robert LeMeur using a twin screw installation developed as a result of a draft limitation imposed on the design. Systems enhancements over those initially tested on the Canmar Kigoriak include the provision of increased inertia to shield the machinery from ice impact transit peak forces and improvements to the control system by way of much faster machinery response times.

4. PERFORMANCE ASSESSMENT

Through extensive full scale monitoring and research programs conducted by Canmar personnel over the past four years, the novel design features incorporated in the Canmar Kigoriak and Robert LeMeur have been evaluated and assessed against design requirements. The information derived from these programs represents a unique source of data on which to assess and determine design criteria. As such, actual results are of proprietary nature. However, a qualitative overview is given in the following sections.

4.1 Level Ice Performance

Improvements in this category are a direct result of the reduced resistance. This reduction is attributable to improvements resulting from the design of the spoon bow and reamers coupled with the reduction in friction associated with the effective use of ice management systems. The result of such innovations and development is that the Robert LeMeur is capable of breaking the same ice thickness near its limiting capabilities as the original hull of the Canmar Kigoriak. This represents a reduction in the power requirement of the order of 40% to break a given ice thickness.

The introduction of parallel vertical sides has been successful in that no detrimental effects have been observed.

The backing performance associated with the undercut stern concept is not as good as that obtained with conventional icebreaker designs.

On the Canmar Kigoriak, backing results in heavy ice/propeller interactions occurring as well as a tendency for the ship to break out of the channels due to the single screw, single rudder installation.

Improvements built into the Robert LeMeur design to overcome these results include a modified stern design incorporating the stern wedge. This has resulted in a significant reduction in the amount of ice being ingested in the propellers whilst backing. The wedge, as presently configured, however does not permit backing in level ice nor does it allow the ship to break out of the channel going astern.

The two designs tested and evaluated to date cover almost the complete range of possibilities in backing performance. From these full scale test results, design criteria may be formulated from which designers can build-in desired backing characteristics into an icebreaker.

4.2 Ridge Performance

Energy considerations govern the performance of icebreakers in ridges. In this context, design development has focused on the vertical stopper or ice knife configuration. Design considerations relate to the need to maximize use of the ships kinetic energy in destroying the ridge while preventing the ship from getting stuck. Two configurations of vertical stopper have been tested in which detailed measurements have been made to derive energy dissipation. These are of significant benefit in determining the optimum design.

The reduced power requirements have a significant bearing on two aspects of ridge performance:

- the reduced available astern thrust increases the need to further study extraction capability requirements, and,
- the lower available thrusts result in slower ship accellerations leading to potentially longer ramming cycles.

Solutions to the above are currently available to the designer through the use of ducted propellers offering much greater thrust at low speed ahead and astern together with the proper application of such ice management system as water lubrication, low friction coatings and heeling systems.

4.3 Ice Management Systems

Numerous auxiliaries to reduce the friction component of resistance have been proposed and/or used. These include heeling and trimming systems, bow propellers, air bubblers, water lubrication, air/water lubrication and low friction coatings. Canmar's experience is based upon the development of water lubrication systems coupled with the use of low friction coatings. These have proven to be very effective and reliable in enhancing performance independently of ships speed.

Similarly, they have also been beneficial in preventing the vessels from getting stuck in ridges. Only under extreme cases has the heeling system been required.

4.4 Manoeuvreability

To date, little research has been conducted into the criteria affecting the manoeuvreability of ships in ice. The turning characteristics of icebreakers are therefore a result of a particular design rather than an input requirement.

Of particular interest are the turning capabilities of the Canmar Kigoriak and Robert LeMeur because of their vertical parallel sides and long parallel waterline at the icebreaking draft. Test results have shown that the turning diameters of both vessels are as good and/or significantly better than state-of-the-art icebreakers depending upon the size of reamers, hull form and the use of heel. This is a particularly important finding when one considers the results of the Manhattan where the turning diameter was found to increase from state-of-the-art levels in 0.9 metre ice thickness to about 80 ship lengths in 1.2 metre ice thickness. Results obtained from the Robert LeMeur which is 1:3.5 scale model of an Arctic VLCC do not show such an adverse trend.

The results of current research based upon test results indicate that turning diameters of the order of 6 ships' lengths in 1.8 metre thick ice are achievable.

4.5 Propulsion System

The introduction of the geared diesel installation driving a controllable pitch propeller on the Canmar Kigoriak has proven to be very successful under year round Arctic service.

The nozzle configuration has been very effective at limiting the size of ice pieces going through the propeller. The protection thus offered significantly reduces the amount and degree of shock loading to which the propulsion system is subjected and permits a propulsion system of standard lower fuel consumption type design to be used. Difficulties associated with the use of nozzle such as loss of thrust due to chocking of the nozzle, can be satisfactorily overcome through careful design of hull form.

The successful use of controllable pitch propellers on icebreakers is a significant development since it provides the same capabilities as a diesel-electric propulsion system with the added benefit of reduced capital cost and reduce risks of sustaining propeller damage during reversals. Enhancements introduced into the Robert LeMeur propulsion system have been most effective at shielding the machinery in the case of the added inertia. The fast response time controls have been beneficial in substantially improving the vessel ramming cycle as well as preventing the ship from getting stuck.

5.0 FUTURE DEVELOPMENTS

Canmar's approach to develop the technology for Arctic shipping has been to proceed in stages based upon full scale developments.

This is because, from experience, model tests and analytical models alone are of limited use in extrapolating the design of Arctic ships.

New concepts for future Arctic ships are being developed based upon the testing and evaluation of Canmar Kigoriak and Robert LeMeur which will provide the performance capabilities at required economical levels for successful resource development. Shown in Figures 4 and 5 are the lastest artist concepts of the Polar X-10 icebreaker and Arctic tanker respectively.

The X-10 icebreaker concept incorporates the latest developments of the features presented and has been conceived for unsupported, unrestricted year round operation with particular accent placed upon relability and performance in ice. The key objectives in developing such an icebreaker are as follows:

1. Pursue the development of technology in stages which are verified in full scale prior to the next step.
2. Demonstrate the feasibility of year-round Arctic marine navigation.
3. Provide full scale input into the development of performance requirements for the full range of Arctic vessels and including multi-year ice.
4. To increase industry's ability to move structures in the Arctic.
5. Provide year round emergency and support services in the Arctic.

From this, arctic marine transportation systems can be developed at lesser risk and cost to industry and government.

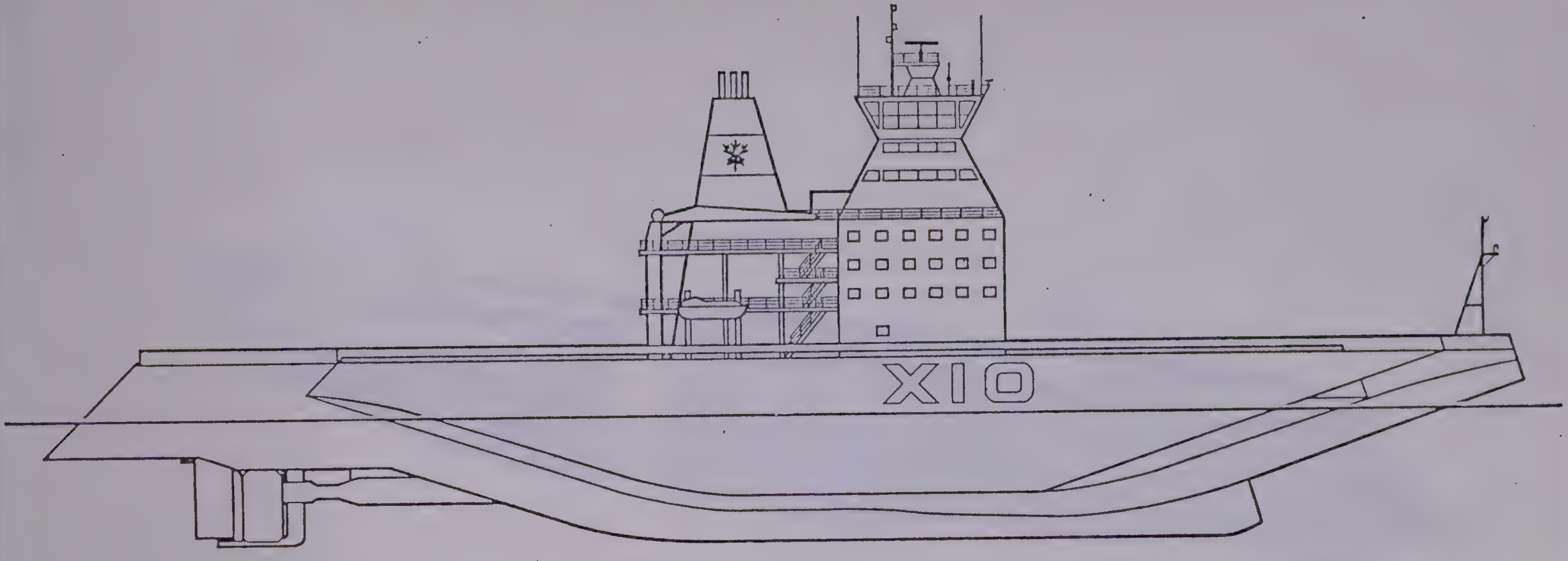


Fig. 4 POLAR X10 ICEBREAKER

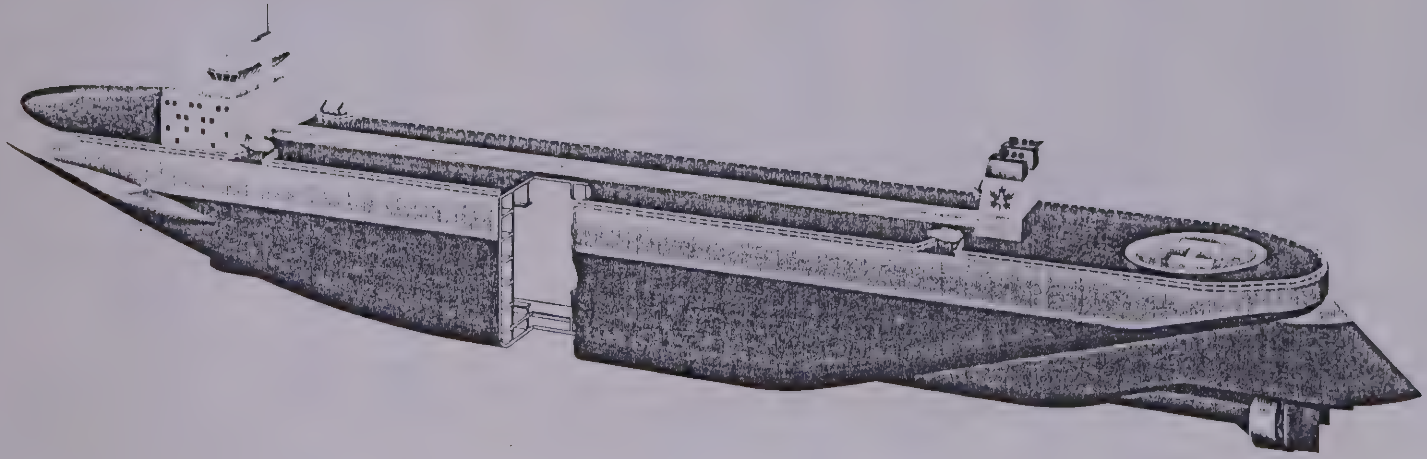


Fig. 5 ARCTIC TANKER

6.0 CONCLUSIONS

6.1 Innovations in hull form combined with the use of ice management systems have significantly reduced resistance in breaking level ice.

6.2 The reduction in resistance associated with the increased thrust available from a nozzle propeller installation has resulted in power reduction requirements of at least one-half to two thirds based upon CASPPR requirements for year round large icebreaking vessels.

6.3 The reamer has proven to be effective at reducing resistance and improving manoeuvering without detrimental effects to astern performance.

6.4 Ice management systems are a cost effective means of improving icebreaker performance.

6.5 The geared diesel driving a controllable pitch propeller has been proven to be a reliable propulsion system under Arctic service conditions.

6.6 The line of icebreaker development pursued by Canmar represents a viable cost effective means of support to Arctic Offshore Exploration.

6.7 A full scale year round navigation demonstration and research program by an X-10 type icebreaker would be cost effective based upon the learning experience gained to date.

REFERENCES

Keinonen, A.J. and Duff, J. "Canmar Kigoriak - Demonstration of Arctic Capability", POAC, 1983.

Churcher, A., Kolomocjev, A. and Hubbard, G. "Design of the Robert LeMeur Icebreaking Supply Ship", SNAME, 1983.

Juurmaa, K. "Icebreaking Advances", The Motor Ship, April, 1983.

Mookhoek, A.D., Voelker, R.P., and DeBord, F.W. "Summary of selected technical results from Manhattan arctic marine project", SNAME, STAR Symposium, 1981.

Date Due

56173

Pam:
629.124.791.2
STU

STUBBS, John T. et al
AUTHOR

Advances in Arctic icebreaker
TITLE
design

DATE LOANED	BORROWER'S NAME	DATE DUE

56173

BOREAL INSTITUTE FOR NORTHERN STUDIES, LIBRARY
THE UNIVERSITY OF ALBERTA
EDMONTON, ALBERTA T6G 2E9
CANADA

University of Alberta Library

0 1620 0336 7735